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FINAL TECHNICAL REPORT

RADIOCOMMUNICATION BY BACKSCATTER

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I. RANZI

CENTRO RADIOELETTRICO SPERIMENTALE "G. MARCONI"
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SUMMARY

Experiments on line-of-sight backscatter of h.f. radio waves put in evidence the high values of the backscattering coefficient, concerning the sea near the coastal boundaries, when the vertically polarized component of the radio wave is considered; it was also shown that the power lines, the railways, and the metallic structures in general are very efficient backscatters, to be considered when the h.f. backscatter occurs from a highly developed country.

Another series of experiments was performed, concerning the possibility to reduce the broadening and the multipath effects in the backscattered echoes, and to increase the bandwidth capability of a radiocommunication system by backscatter; it was shown that the echo pattern strongly depends on the antenna vertical beamwidth, and that the ionospheric irregularities producing multipath effects are of the focusing type: their occurrence notably increases with the latitude.

1. *Introduction.*

As known, the propagation of radio waves may occur over paths other than the great-circle path between stations, particularly when a ground scatter occurs between two successive ionospheric reflections.

Since 1928, such a phenomenon was observed by *Taylor* and *Young* (1); in 1939, *Feldman* (2) observed bearing deviations of the received signal up to 80 degrees off the great circle path during tests between London and New York on 5 and 15 Mc/s.

Edwards and *Janski*, in 1941, (3) put in evidence ground scatter phenomena in a multihop path.

The possibility of establishing a communication link by means of a ground-scattered propagation was shown in 1956 by *Hedlund, Edwards* and *Whitcraft* (4).

One the other hand, Japanese researchers (5, 6, 7) performed studies on groundscatter effects in long distance h.f. circuits, as the London-Tokyo, and Hawaii-Tokyo circuits; they devised a method of prediction, including the effects of a southerly deviation of the non-great-circle propagation.

An important and interesting research on the application of the groundscatter propagation to communication purposes was recently performed by R.T. Wolfram (8, 9). In these experiments, a transmitting station was operated at Bozeman, Montana, and receiving station at Palo Alto, California, and the directive antennas at the two stations were programmed to scan all possible propagation paths in a five-minute period; the contemporary presence of two different non-great-circle paths was put in evidence, and the strength of the received signals appeared to be sufficient to support a communication link.

The groundscatter propagation of h.f. radio waves may improve communication systems, in two ways:

a) When the skip distance for the used frequency exceeds the distance between the two stations of the link, it is possible to establish the communication by directing the antennas to a convenient point of the skip zone, where the ground backscatter may occur.

b) Even when the great-circle path may be used, the possibility to have other paths available may increase the number of channels, by distributing them in some different directions of communication; the same possibility may help to reduce the effects of interference.

The purpose of this research was to determine the influence of the nature of the ground, wherefrom the backscatter occurs, on the intensity of the backscattered echoes and to identify the factor producing the broadening of the backscattered pulses when they are reflected from the F2 layer.

The importance of these elements for the practical application to communication purposes in evident; in particular, the multipath effects, and the ionospheric irregularities, producing a broadening of the backscattered pulses used in the sounding, are worth an accurate study, as they define the maximum bandwidth usable in the communication system.

During the research, echoes backscattered via sporadic-E where observed and recorded; the first results of a study performed on the characteristics of this kind of backscatter was published in the Technical Note No. 9 (10). In this Report nothing else is referred.

The presence of the echoes backscattered via Es produces a very troublesome multipath effect in a communication link based on the backscatter via F2 layer; in such an occurrence, only an appropriate frequency scaling technique (of the type employed in ionoscatter links, in order to avoid the effect of backscatter via F2 layer) may keep the communication efficiency.

As this phenomenon is a transitory one, it will not be considered in the present Report, the purpose of the Report being to state some characteristics of the backscatter via F2 layer, from the point of view of the application to a radiocommunication link.

2. *Experimental equipment.*

Fo the long distance backscatter (via ionosphere) experiments, two similar sounders, were used, the one working on the frequencies of 18.6 and 22.3 Mc/s and the other one on 14 Mc/s.

The pulse length was generally about 350 μsec, with a repetition frequency of 16.6 c/s: the emitted peak pulse power was about 4 kW.

For the line-of-sight backscatter experiments, on frequencies between 4 and 14 Mc/s, an ionospheric sounder of a conventional type was employed (pulse length of 50 μsec, peak pulse power of 4 kW about).

In the same experiments and for the higher frequencies, various experimental equipments were built, having a pulse peak power from 0.5 to 1 kW, and a pulse length from 5 to 10 μsec: some of these « radars » were easy to be transported and operated with battery supplies.

Rotating four-elements Yagi antennas were used on 18.6 and 22.3 Mc/s; in the last period a rotating Yagi antenna was placed on the top of a tower at the height of 54 m above the sea level (49 m above the ground level, being the distance of the tower from the coastal boundary of about 10 m).

A rhombic antenna of 60 m side, placed at the height of 13 m above the ground, was also employed in some experiments.

3. *General characteristics of the backscatter via F2 layer, as observed in the experimental station of Torrechiaruccia.*

During the period between about April and September, the echoes, due to the ground backscatter via ionosphere, show a complex pattern due to the contemporary presence of reflections from F2, F1 and, sometimes, E_s layers; only by using an appropriate frequency band, it is possible to separate the echoes reflected by the F2 layer alone.

As our study is limited to the backscatter via F2 layer, the great majority of the records considered are referred to the periods from October to March of each year.

The backscatter sounding began on August 1958, with fixed and rotationg antennas, and generally on the frequency of 22.3 Mc/s; in March 1961 the frequency had to be reduced to 18.6 Mc/s and to 14 Mc/s, as a consequence of the decreasing solar activity.

From our first records an azimuthal distribution of the intensity in the backscattered echoes propagated via F2 layer, was observed, like the one showed by the record, reproduced in Fig. 1; a maximum of the intensity and of the duration of the echoes coming from NNW and minima from SSW and from NE were remarked; a secondary maximum was observed from SE.

To remove the doubt that this azimuthal distribution of the echoes intensity was due to the local influences (obstacles, orientation of the coast, etc.), some recordings were made at the same time by means of two backscatter sounders, the one at Torrechiaruccia and the other one at S. Marinella, where the orientation of the coast is a very different one: these two points are marked as A and B in the map of Fig. 2. It is to be remarked that the experimental station of Torrechiariuccia is very near to the coast, and the distance of the antenna tower from the sea is about 10 m.

Another series of contemporary records was performed at Torrechiaruccia and at a locality near Rome (S. Alessio, Fig. 2), placed in a flat land.

In all these cases, the azimuthal distribution of the echoes intensity was very similar.

We may deduce that the cause must be found in the ground backscatter or in the structure of the ionospheric reflecting zone.

The main maximum of the backscattered echoes intensity corresponds to a zone including the north of Europe, England and the Atlantic Sea; the two minima correspond to the Russian continent and to the African desert. It is to be remarked that generally the ground distances, from which an observable backscatter via F2 occurs, when use is made of an antenna height of the order of one wavelength, are between about 1000 and 3000 km (the more intense backscatter occurs from 1200 to 2400 km about).

After this first observation, the research was addressed to determine the influence of the ground nature on the backscatter of h.f. radiowaves and the influence of the ionospheric structure on the pattern of the backscattered echoes.

The results of our study appear to show that the observed azimuthal distribution of the backscattered echoes intensity may be explained on the ground of the low values of the backscatter coefficient concerning land and desert as compared with the ground reliefs, with the coastal boundaries and with the sea surface.

The greater broadening of the echoes coming from the northerly directions appears to be produced by the ionospheric irregularities which are more remarkable on the higher latitudes.

4. *Influence of the nature of the ground on backscatter.*

While an enhanced backscatter from mountain chains (11) is evident, there is a lack of data as to the differences between the backscatter coefficients of land, sea, and coast lines.

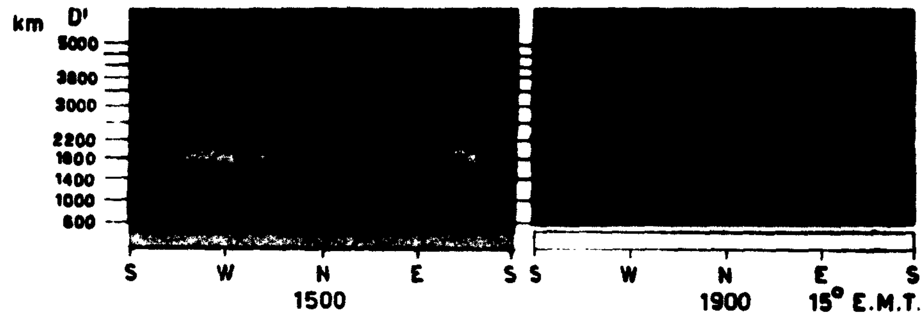

Fig. 1 - *Typical backscatter soundings, on 22,3 Mc; January 29, 1959*

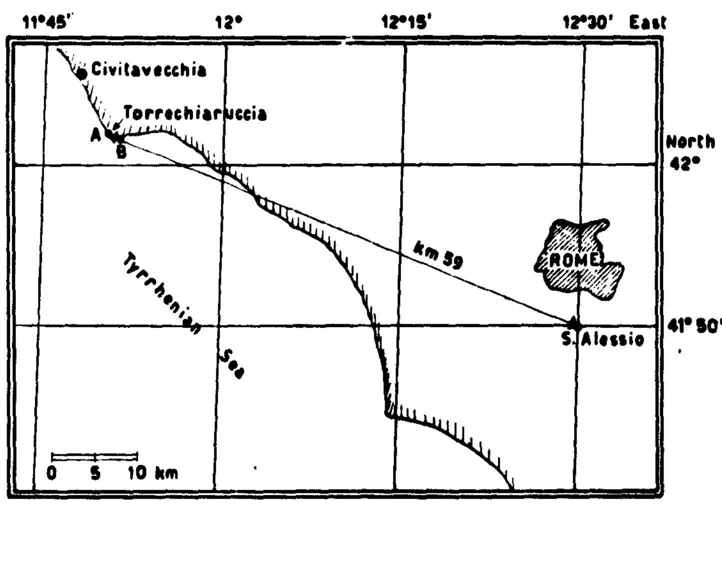

Fig. 2

Kabanov (12) observed in Moscow a strong enhancement of the echoes backscattered from the coastlines of the Black Sea. This observation appears to be in agreement with the results of an interesting series of experiments performed by *D. Nielson, G. Hagn, L. Rorden* and *N. Clark* (13) on the line-of-sight backscatter from the earth surface; an airborne radar on 32.8 Mc/s was used to investigate the backscattered radio energy: the results show that the electrical properties of the terrain lose their importance at low aspect angles, while both roughness and electrical properties are important at high aspect angles; water, smooth ice, and mixed land and water surfaces gave higher return, by using vertical polarization; coastlines produced stronger echoes whith horizontally polarized signals, while the backscatter from land surfaces did not appreciably change with polarization.

A series of experiments on line-of-sight backscatter of h.f. radio waves from open and coastal sea and from ground reliefs was performed, the results of which were reported in the Scientific Note No. 3 (14) and (15).

The more important results may be summarised as follows.

4.1. *Backscatter from the sea surface.* Experiments were performed on 4, 7, 10 Mc/s, by using a 50 μ sec pulse sender, having a peak power of 4 kW and feeding a $\lambda/2$ dipole, installed on the coastal boundary; a conventional pulse receiver with a loop antenna and connected to a c.r. oscilloscope was used to determine the range, the amplitude and the direction of arrival of the echoes.

Experiments were performed even on the frequency of 28 Mc/s, by means of a 5 μ sec pulse sender, having a peak power of about 1 kW; a 3-elements Yagi antenna was used as a common transmitting and receiving aerial.

The horizontal backscatter of h.f. radiowaves from the sea surface is practically observed only with vertically polarized radio waves; the sea echoes intensity on 28 Mc/s may lower by about 28 dB, whilst changing from vertical to horizontal polarization.

The backscattered radio waves show a Doppler frequency shift Δf due to the coherent backscatter from the component of the sea waves having a mechanical wave length equal to the half radio wave length: as $\Delta f = \frac{2V}{\lambda}$, where V is the velocity of the sea waves having a length $L = \frac{\lambda}{2}$, and as $V = \sqrt{\frac{g}{2\pi}}$, we have:

$$\Delta f = \frac{g}{\pi \lambda}$$

In order to have a rough evaluation of the backscattering properties of the sea surface, we considered the « apparent reflection coefficient ρ », simply defined as the ratio between the mean field strength of the echo horizontally coming from a given backscattering zone, placed at the distance d/2 from the radar station and the field strength, which should have been produced by the surface radio wave at a distance d from the same sender, along a sea path.

With a very rough sea, on 4 Mc/s, a maximum value of ρ equal to $8 \cdot 10^{-2}$, and on 28 Mc/s a maximum value of $3 \cdot 10^{-2}$ were observed; the minima, with a very

calm sea, were lower than 10^{-4} on 4 Mc/s, and about 10^{-3} on 28 Mc/s. The pattern of the echoes, backscattered from the sea surface, appears to be a spiky one; besides, some outstanding echo groups, having a continuously changing position, were often observed.

4.2. *Backscatter from the coastal sea.* The sea waves near a costal boundary produce a stronger backscatter than the one due to the open sea waves; the backscattered energy does not show any Doppler frequency shift, but it periodically fades with a frequency equal to the Doppler frequency shift Δf produced by the open sea on the same radio frequency. Such a phenomenon may be due to a system of stationary sea waves formed near the coast: the periodic oscillation of the sea surface at the antinodes may produce the observed fading.

The most important feature of such a backscatter consists in its intensity, rapidly increasing with the sea roughness, and reaching values much higher than the ones concerning the open sea waves.

An outstanding result was obtained during some experiments performed on 4 Mc/s by placing the pulse sender at Torrechiaruccia and the receiver at the foot of Argentario's promontory (Point A, Fig. 3); when 50 μ sec pulses were emitted, with a peak power of 4 kW, from a vertical $\lambda/2$ dipole, echoes due to Giglio's, Montecristo's and Elbas' island where observed, such echoes showing a remarkable increase of their amplitude (and of fading) with the sea roughness.

In Fig. 4, the record *a*) was obtained at noon in a day of an exceptionally calm sea (December 1, 1960); the record *b*), at noon too, in a day of rough sea (December 7, 1960), the receiver sensitivity being 12 dB lower than the one used for the record *a*).

The intensity of the echoes backscattered from the sea may increase by more than 10 dB when the backscattering zone passes from the open to the coastal sea; a maximum value of ρ equal to 0.3 may be reached.

The same phenomenon was observed on the frequency of 28 Mc/s.

If this results is applied to the interpretation of the strengthening of the echoes backscattered from coastlines via F2 layer, it is to be taken into account that the strengthening, observed in the backscatter from coastal sea, occurs only in the vertically polarized component of the radio wave; as the ionospheric reflection generally produces an ellyptical polarization state of the downcoming wave, the vertically polarized component may be sufficient to explain some experimental results, even when the emitted wave is horizontally polarized.

A strengthening of the echoes due to the backscatter from sea near the England coasts may contribute to produce the azimuthal distribution observed in the backscatter intensity.

4.3. *Backscatter from ground reliefs and from metallic structures.* As referred in the Technical Note No. 4, some experiments were performed on the line-of-sight backscatter of 28 Mc/s radio waves from different ground reliefs. In agreement with the results obtained by *D. Nielson* and all. (13), above referred, remarkable increase in the intensity of the echoes was observed due to a ground relief near the coast, when a sea surface was placed between the radar and the target, and use was made of horizontally polarized radio waves; the height of the radar antenna above the sea surface was such a one than the maximum of the field strength corresponded to the top of the ground relief.

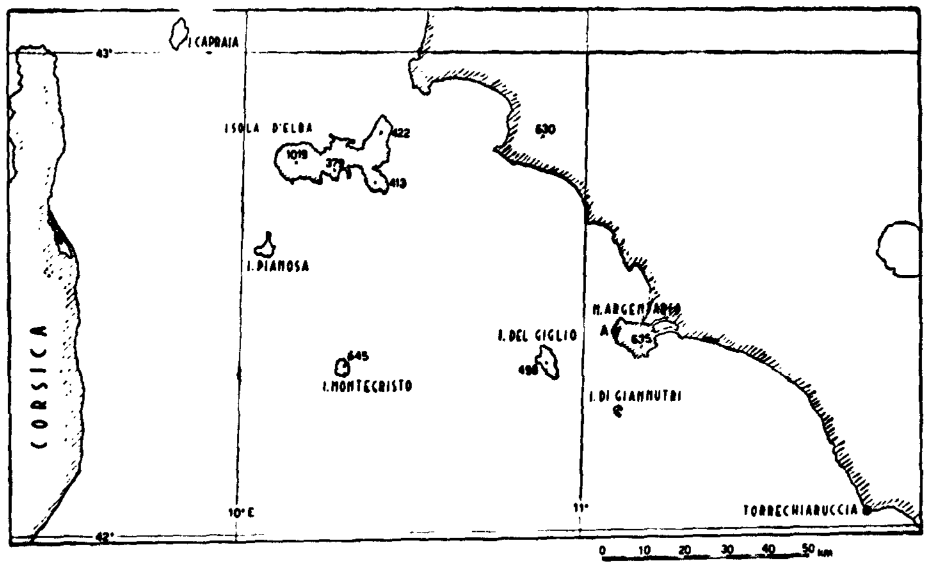

Fig. 3 - *Map of the zone in which the records of* Fig. 4 *were obtained (heights of the ground reliefs are in meters).*

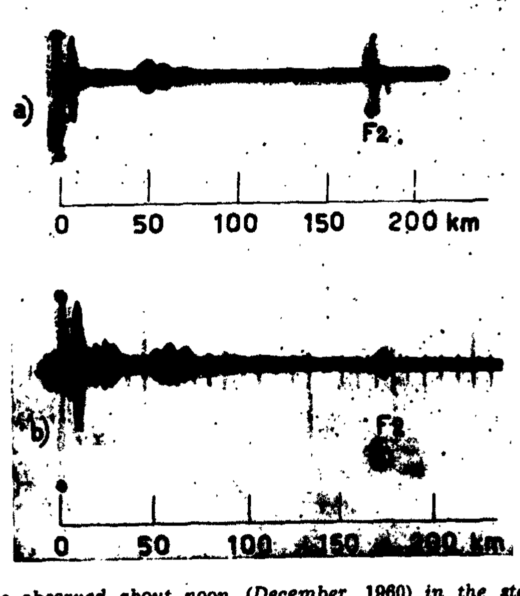

Fig. 4 - *Echoes observed about noon (December, 1960) in the station A, when the pulses were emitted from Torrechiaruccia, on 4.1 Mc/s. The record* a *was taken with a calm sea: the record* b, *with a rough sea, the receiver sensitivity being 12 dB lower than for record* a. *The distance scale gives the difference between echo and direct pulse paths, divided by 2. The first echo, corresponding to an equivalent distance of 10 Km, is due to Giglio's island.*

By changing the polarization of the radio waves from the vertical to the horizontal one, the intensity of the echo due to the ground relief, showed a stronger increase than the one expected from the variation of the field intensity on the target (as known, this variation is due to the increase of the reflection coefficient of the sea surface when passing from the vertical to the horizontal polarization).

The presence of electric power lines, and of some antenna installations at the top of the mount, may explain the observed change.

A further examination of the results concerning our experiments on direct backscatter of h.f. radio waves led us to consider the great importance of the metallic structures, and, in particular, of the electric lines and of the railways, which are very efficient scatterers; their presence in some highly developed countries may remarkably contribute to the backscatter of the ionospherically reflected radio waves.

In the Scientific Note No 4 (15), the results of an experiment performed in front of Mount Soratte (near Rome) with a 28 Mc/s radar was referred.

The map of the zone is reproduced in Fig. 5 and in Fig. 6 the echo pattern observed at the point A is reproduced, when the radar antenna was directed to the mountain top, and the vertical and the horizontal polarization were used.

As expected, the echo from the power line enhances with the horizontal polarization; its sharpness shows that it comes only from the first Fresnel zone, the horizontal extension of which being about 100 m; even the echo from the steepest zone of the mountain side (the more distant echo, coming from about 7.2 km) is a very sharp one, and therefore shows its origin in a restricted ground area. If it is considered that the electric line is at about half a way between the radar and the mount, it is to be deduced that the backscatter cross sections of the line and of the scattering mountainous zone are of the same order of magnitude.

Probably the components of the radio wave energy scattered from the various elements of the line did not arrive with the same phase at the radar antenna; a coherent backscatter should have produced a stronger echo. The incidence of the radio waves on the steepest zone of the mount side occurs under an elevation angle of about 45°; in the long-distance ground backscatter of h.f. radio waves reflected from the F2 layer, the elevation angle (referred to an horizontal plane) may vary from 5° to 15°, and the mountain slopes are generally lower than 45°, so that the parameters of the described experiment may correspond to the average conditions of the long distance backscatter.

A rough determination of the backscatter cross section corresponding to the echo from the power line, as observed in the reported experiment, leads to a value of 250 m^2, this one being referred to a line length of about 100 m (the length of the first Fresnel zone).

The echoing area of the ground in a long distance backscatter experiment was evalutated to be of the order of 10^7 m^2 (16), so that a total length of 5.000 km of wire lines may explain the observed intensity of the backscattered echoes; a great contribution to the backscatter is to be expected even from railways and from other metallic structures.

5. *Influence of the vertical radiation diagram on the backscatter echo pattern. Application to the backscatter communication systems.*

As previously referred, the echoes backscattered from directions between N and W,

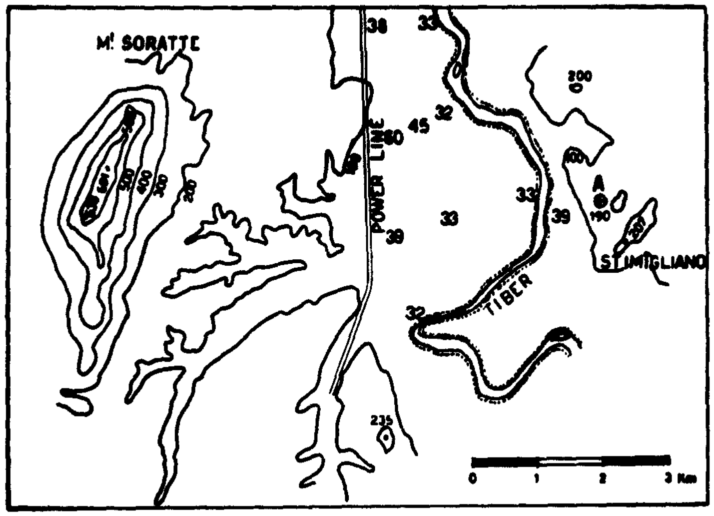

Fig. 5

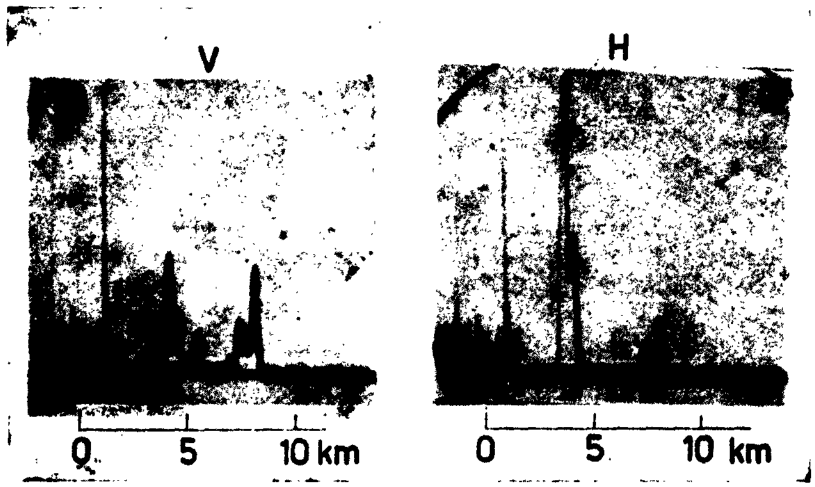

Fig. 6 - *Echo patterns on 28 Mc/s, with radar in* A (Fig. 5); *the strong echo from 3.5 km is due to the power line; the echo from a target distance of 7.2 km is due to Mount Soratte.*

show a remarkable increase of their duration, so that a communication link based on such a backscatter should have a very reduced bandwidth capability.

The lengthening of the backscattered echoes pattern may be due to the following causes:

a) a very high backscatter coefficient of the ground, so that the radio wave energy backscattered from the earth surface even beyond the skip limit (where the skip focusing occurs) may be revealed; the focusing irregularities occurring in the ionosphere may enhance the backscatter from zones placed beyond the skip limit;

b) a multipath effect due to a diffusion produced by the reflecting region of the ionosphere, as a consequence of the irregular ionospheric structure; in this case, the echo may come from a restricted earth area near the skip limit, the diffusion being operated only by the ionospheric irregularities.

In the first case, it is possible to reduce the broadening of the echoes, by a suitable narrowing of the vertical radiation beamwidth, if there are no focusing irregularities in the ionosphere.

To put in evidence the influence of the vertical radiation diagram on the echo pattern, a horizontal Yagi antenna was placed at the height of 54 m (3.38 wave lengths, for the frequency of 18.6 Mc/s) above the sea level; as the antenna tower is installed at the end of a cape, the whole first Fresnel zone lies along the sea surface, when the antenna points to directions comprised between NNW and SSW; as a consequence, the vertical radiation diagram shows, in these directions, sharper lobes than in the other one , where the first Fresnel zone lies along an irregular terrain surface.

The calculated elevation angles of the two first lobes are 4.2° and 12.8°.

In Fig. 7a an example of the records obtained in an ionospherically calm day (February 2, 1952) is reported, the antenna being pointed to a SW direction.

The geometrical parameters, to be considered in the case of a well defined vertical radiation lobe, having an elevation angle β above the horizontal plane, are the following: the incidence angle α of the same lobe in an horizontally stratified ionosphere, the virtual reflection height h', the ground great circle distance D of the backscattering zone from the sounder, the virtual or equivalent oblique distance $D' = \frac{\tau c}{2}$, where τ is the echo time delay, the earth radius a.

is the echo time delay), the earth radius a.

The relations are then as follows:

$$\sin \alpha = (\cos \beta) \left[1 - \frac{h'}{a} + \left(\frac{h'}{a}\right)^2 - \left(\frac{h'}{a}\right)^3 + \ldots\right]$$

$$D = 2a \left(\frac{\pi}{2} - \alpha - \beta\right)$$

$$D' = 2a \frac{\cos(\alpha + \beta)}{\sin \alpha}$$

As β is known, α may be determined through the experimental measurement of D': the real distance D of the backscattering zone and the virtual reflection height h' may be then calculated.

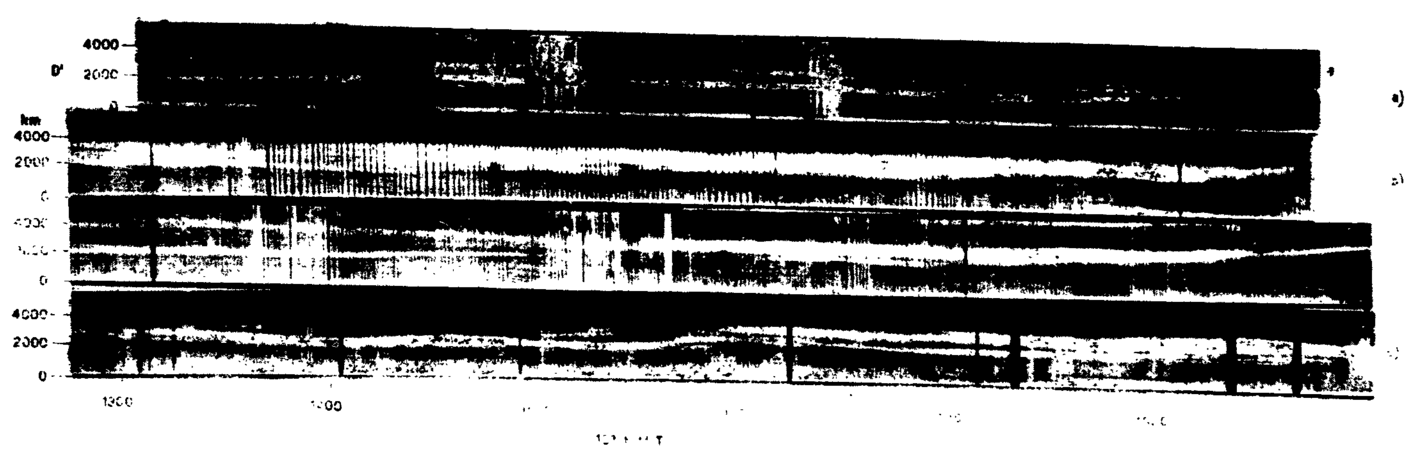

Fig. 7 - *Fixed direction records on 18.6 Mc/s.* a) *SW, Febr. 2, 1962; two maxima corresponding to the two first antenna vertical lobes; focusing effect at sunset.* b) *NW, Febr. 1, 1962; focusing ripples.* c) *SW, Febr. 6, 1962; presence of a strong horizontal gradient of electron density, around 1400 hrs.* d) *NW, March 3, 1962; localized variations of electron density.*

In the record of Fig. 7a, at 1400 hours, the values of D' corresponding to the two first antenna lobes, where 2100 and 2900 km, respectively, and the virtual reflection heights calculated to be 310 and 260 km, respectively. The same record shows, after 1800 hours, the overlapping of the two maxima, due to the sunset decrease of the electron density: the focusing effect at the skip distance is clearly demonstrated.

When there are no ionospheric irregularities, it is possible to reduce the echo broadening by using a narrow beamwidth in the vertical plane.

It will be seen, in the next paragraph, that ionospheric irregularities may produce multipath effects, but, even in this case, a reduced vertical beamwidth may improve the situation.

Our experiments show that the broadening of the echoes is not produced by an ionospheric diffusion, but that it is due to a changeable ionospheric focusing of the energy backscattered from the ground at a certain distance from the skip zone.

6. *The effect of the ionospheric irregularities.*

The kind of irregularities more frequently observable is the one shown by the record of Fig. 7b, obtained with the same experimental device described in the preceding paragraph; the echoes corresponding to the first and to the second antenna lobe are no more separated, and a series of focusing « ripples » move from the lower ionosphere (where the first antenna beam is reflected) to a higher ionospheric zone being nearer the sounding station. This record was obtained on February 1, 1962 (the Yagi antenna being directed to NW, and the working frequency equal to 18.6 Mc/s.

In Fig. 8 other records obtained on 22.3 Mc/s, during the period December 1958-February 1959, through the use of a rhombic antenna directed to N are reproduced. These records show the presence of moving focusing ripples, sometimes enhancing the echoes propagated in a two-hop mode.

This type of irregularities generally produces a broadening of the echoes and multipath effects.

During the period from January to March 1962, contemporary records of the echoes backscattered from the NW and from the SW direction, on the frequency of 18.6 Mc/s were performed, the frequencies of the two sounders differed of about 50 kc/s and the pulse modulation of the two senders was synchronized.

The number of ripples and their amplitude were higher in the backscatter from the NW direction than in the one from the SW direction.

Such a result shows that, for an intermediate latitude backscatter link, in the northern emisphere, the more convenient beckscatter directions are the southerly ones.

The characteristics of these small scale irregularities were studied, through a backscatter technique, by *L. H. Tveten* (18), who attributes the focusing effect to concave wrinkles produced in the F2 layer.

The median apparent speed of such wrinkles is of the same order of magnitude as the one resulting from our record (400 km/hr); even the quasi-periodic behaviour of the irregularities, as observed by *Tveten*, is shown by our records.

More information about the form and the focusing characteristics of these ionospheric irregularities may be obtained by contemporary backscatter sounding and vertical ionospheric sounding, this last one being performed near the ionospheric zone reflecting the backscattered echoes; to this purpose, we are performing, since August 1, 1962, records of the echoes backscattered on the two frequencies of 14 and 18.6 Mc/s, from

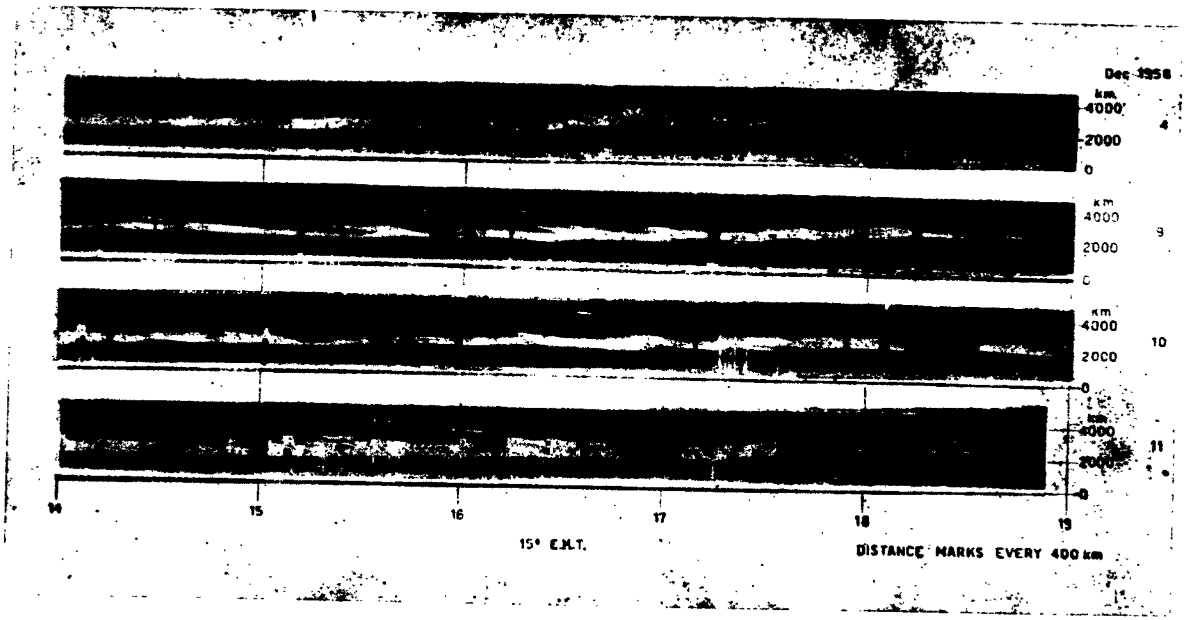

Fig. 8 - *Records on 22.3 Mc/s, taken in the N direction (rhombic antenna, 13 m above the ground).*

the direction of the ionospheric station of Breisach (Germany), which is placed at the distance of 740 km from our station in the NNW direction. It is planned to compare the different records, especially when the backscatter sounding shows clearly defined ripples; the study will be continued until the next March, as during the winter period the backscatter mainly occurs via F2 layer, and the echoes show a simpler pattern.

Another type of ionospheric irregularities, probably of a large scale structure, was observed by means of the vertically split beam technique. Examples are given in Fig. 7c and in Fig. 7d.

The record of Fig. 7c, taken on Febr. 6, 1962, in the SW direction, shows, at about 14000 hours, a strong difference between the two values of D', which were 1900 and 3200 km, respectively; through the formula given in the paragraph 5, the corresponding virtual heights are calculated to be 275 and 310 km, the first one corresponding to the higher emitted beam (12.8° of elevation), the second one to the lower beam (4.2° of elevation); a very strong horizontal gradient of electron density may be present at that time in the reflecting zone.

The echo pattern shown by Fig. 7d (March 3, 1962, NW direction) reveals the presence of localized increases or decreases of the electron density, or changes concerning the vertical gradient of the electron density, and occurring in different amounts along the line passing through the two ionospheric reflecting zones.

7. *The influence of ionospheric storm on the backscatter.*

The results of our researches on this subject were referred in the Scientific Note No 5 (19).

8. *Conclusions.*

In a radiocommunication link based on the ground backscatter of h.f. radio waves, the bandwidth capability of the system may remarkably increase, when use is made of antennas having a narrow beamwidth in the vertical plane.

In the northern intermediate latitude, the multipath effects due to the focusing irregularities in the F2 layer may be reduced, if the backscatter occurs from southerly directions.

As to the influence of the ground nature on the intensity of the backscattered sisignals, the sea near the coastal bundaries shows a very high backscatter coefficient for the vertically polarized component of the h.f. radio waves, and this coefficient rapidly increases with the sea roughness.

Power lines, railways and metallic structures are very efficient backscatterers, to be considered, when the backscatter occurs from a technically developed country.

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